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TARGET ACQUISITION DURING A MANNED REAL-TIME RECONNAISSANCE MISSION

MARCH 1981

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AERONAUTICAL SYSTEMS DIVISION
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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This technical report has been reviewed and is approved for publication.

MARY E. WEAVER, Project Officer
Operations Research Group
Directorate of Mission Analysis
Deputy for Development Planning

RICHARD E. WORTHEY, Chief
Operations Research Group
Directorate of Mission Analysis
Deputy for Development Planning

RICHARD K. TRASK, Director
Mission Analysis
Deputy for Development Planning

S. A. TREMAINE
Deputy for Development Planning

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During a manned real-time reconnaissance mission, providing target information to our military intelligence in a timely, efficient manner is of prime importance. In order to assess target information, the human observer is faced with many influencing variables. The main variables involved during target acquisition consist of the target/background, aircraft, environment, sensor display unit, and the human observer himself. Additionally, for each variable are many other elements which have some influence on the target acquisition process. This independent research paper briefly covers some of the important aspects

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FOREWORD

This Independent Research paper was prepared as part of my training programs during the period 28 August 1980 to 28 February 1981. The objectives were also to familiarize me with the functions, capabilities, and limitations of the human operator in the air-to-ground target acquisition mission, and to expose me to related working areas within Area B, of Wirght-Patterson Air Force Base, Ohio.

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INTRODUCTION

With the development of a wide variety of aircraft specialized for particular missions during World War II, certain recurrent human operator problems developed. One of the most recurrent problems was associated with finding ground objects from the aircraft. As a remedy to many of the operator problems, the prediction of target acquisition has been found to be essential in planning reconnaissance missions because of the generally limited time available from the air, the high cost of sustained search, the serious consequences of failures and mistakes, and man's exposure to the hostile environments.

Target acquisition in a real-time reconnaissance mission generally occurs during the prehostility period when information is gathered of our enemy defenses within a period of minutes to a day. The search for this information may involve an effective method of penetrating deep into enemy territories at various altitudes (preferably at the lower altitude), during all types of weather and at day or night time hours.

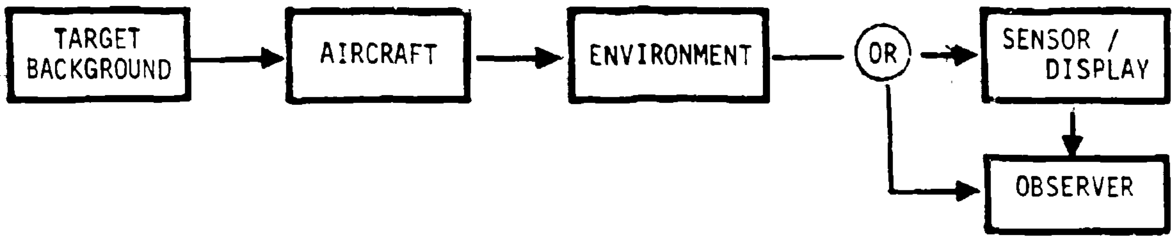
During the acquisition stage of the mission, the manned air-to-ground search includes the target and its background, the aircraft, the human observer, and the sensor and the display unit (Model 1). The observer's task during this process is to search the display and/or ground in locating targets of interest. In assessing the disposition of targets and enemy forces, such devices as image intelligence (IMINT) and electronic intelligence (ELINT) are used to assure optimal usage of the airborne and ground-based forces. IMINT involves the use of sensors; such as, cameras, infrared line scanners, and radars to produce an image on a display of the enemy forces. ELINT seeks to determine the disposition of enemy transmitter sites.

What are the essential factors considered in assessing a target of interest? Listed in Model 1 for each block are the key factors which have some influence on each parameter during target acquisition. The parameters, including their influencing elements, all interact affecting target acquisition performance. It is the goal of this paper to cover some of those important parameters influencing the probability of the observer acquiring the target of interest during an air-to-ground reconnaissance mission.

OBSERVER PREPARATION

Before a reconnaissance mission commences, there is a certain amount of information an aerial observer should know in assessing the target in a timely fashion. Factors which are key to an observer's understanding

MODEL 1



TARGET BACKGROUND PARAMETERS	AIRCRAFT PARAMETERS	ENVIRONMENT PARAMETERS	SENSOR/DISPLAY PARAMETERS	OBSERVER PARAMETERS
TYPE	ALTITUDE	VISIBILITY	SENSOR TYPE	FIXATION
SIZE	RANGE	CLOUD COVER	FIELD-OF-VIEW	SEARCH TIME
SHAPE	SPEED	SUN ANGLE	RESOLUTION	SEARCH PATTERN
CONTRAST	OFFSET	ILLUMINATION LEVEL	CONTRAST RATIO	VISUAL ACUITY
TEXTURE	TARGET EXPOSURE TIME	DIURNAL VARIATION	GAMMA	EXPERIENCE
MOTION	TYPE AIRCRAFT	SEASONAL VARIATION	SIGNAL-TO-NOISE	TRAINING
SHADOW	CREW SIZE	SCINTILLATION	FRAME RATE	EXPECTATION
TERRAIN TYPE	SEAT POSITION	GLARE	INTERLACE	MOTIVATION
VEGETATION	APPARENT MOTION	ATTENTION	INTEGRATION TIME	TASK LOAD
MASKING		TRANSMITTANCE	POINTING ANGLE	STRESS
CLUTTER		APPARENT CONTRAST	DISPLAY SIZE	NUMBER OF OBSERVERS
CAMOUFLAGE		MTF	ASPECT RATIO	PREBRIEFING
DISTINCTIVENESS			VIEWING DISTANCE	CUEING
EMBEDEDNESS			DISPLAYED SIGNAL-TO-NOISE	SEARCH AIDS
CUES			COLOR	
CONFUSEDNESS			ENHANCEMENT	
			SCENE ROTATION	

of a mission requires specialized training as well as immediate preflight briefings. The objective of the specialized training, is to train the observer to correlate and interpret the sensed data on the display in terms of past experience. The sensed data on the display may be symbolic or may look very similar to the object on the ground. The training will, therefore, provide this information to the observer in photographic, radar, or infrared pictures in order for the observer to become familiar with the key target-identifying cues in all of these picture type modes.[1]

[1] Haugen, R., et al. Operator Performance in Strike Reconnaissance. WADD Technical Report 60-521, Wright Air Development Center, WPAFB, OH, Aug 1960. Pages 13-14 (Here and after refer to Haugen, R.).

In addition, exposure to the terrain features of the target area, as well as target signatures during the prebriefing session, is beneficial to the observer in directing his eye movements. Visual fixations of the eye consist of a sequence of both learned and natural eye movement search patterns. Natural search patterns consist of the eye jumping (saccadic) from one position to another. If the observer has been prebriefed on certain target signatures (size, shape, contrast, etc.), this information will determine the path of movement of the eyes and the stopping point according to Williams data (ref [2]). Simultaneously, Snyder's data (ref [2]), reveals that the characteristics of the target's surrounding area (terrain features) are also important in directing eye movements. Training the observer in a particular search pattern, should also help reduce wasted time during target acquisition. According to Thomas and Caro (ref [2]), performance was directly related to the type of search pattern the observers were instructed to use. For example, head movement directing the line-of-sight from the horizon abeam the aircraft, and back outward at a fixed rate (side movement method), produced significantly better identification of targets than (in descending order) the forward movement method, the forward fixed method, or the side fixed method. In the forward movement method, the observer "looked forward at a 45 degree angle to the line-of-flight initially, and then swept his gaze back toward the rear of the aircraft." In the forward fixed method, the observer looked at the same 45 degree angle to the line-of-flight, but did not move his head. In the side fixed method, the line-of-sight was fixed 90 degrees to the line-of-flight and downward.[2]

Also, prior to a reconnaissance mission (in addition to the observer's training), an observer is usually prebriefed as to the general area of the target and any beneficial information that will assist him during his search and identification of the target. If a great deal of information is available, such as pictorial representations (possibly obtained on an earlier reconnaissance mission) of the target and general area, this representation can be matched with a view obtained during an actual mission. Furthermore, there are additional levels at which information may be provided to the observer. The observer may be told:

1. To indicate any military targets that he sees;

2. To find a particular target, identified by type;

3. To analyze some specific information about one point of the target or some characteristics of the immediate area;

4. The targets approximate distance and direction from a recognizable land mark along the run (target location); or

5. To find more than one target and more than one kind of target (he also may be given misinformation).[3]

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[2] Marietta, M., Air-to-Ground Target Acquisition Source Book, Office of Naval Research, Arlington, VA, September 74. Pages 5.2-5.5 (Here and after refer to Marietta, M.).

[3] Haugen, R., page 14.

Prior to the prebriefing session, it is decided whether the mission will utilize a one-man system or a two-man system (also dependent upon the cockpit size). If a one-man system is used, the problem entails a balance between the desirability of less weight and improved aircraft performance versus the limitations of a single man search. With limitations on the type of targets to be searched, and with automatic flight control systems, map-matching techniques and terrain-avoidance equipment (as found in the F-16), the pilot could devote a significant part of his time to observation. On the other hand, if a two-man system is used, the pilot might share some of the reconnaissance responsibility with the full-time observer by dividing up the job as follows:

1. The pilot might view a broad field on a forward-looking radar and delineate the area to be searched by the second man;

2. The two crew members may divide the area to be searched;

3. The job might be divided by having each man look for a specific type of target, with the most occupied man only given the more obvious targets; or

4. Both might scan the entire display, so that between them nothing would be missed.[4]

Whether the mission incorporates a one-man system or a two-man system, all information has to be quickly reported to the ground-based stations.

THE TARGET IDENTIFICATION (ID) VARIABLES

Once the crew has attained some training and has been prebriefed on the mission goals, the actual target acquisition phase begins. In assessing available information, a thorough understanding of certain variables will increase the probability of detection and recognition of a target.

The variables involved during target acquisition are shown in MARSAM Model 2. The four main parameters (in addition to their influencing elements) determine the probability of detection and recognition as follows:

1. Search involves close observation of one or a few points for specific information. During the search period, the P1 variable, probability of fixating and dwelling upon a target element, is dependent upon the search area, available time, line-of-sight (PLOS), time and glimpse allocation, and time-varied conditions;

2. Target detectability, P2, involves the awareness of local energy differences in the observer's visual field, and is further influenced by contrast and size, luminance, and distinctiveness;

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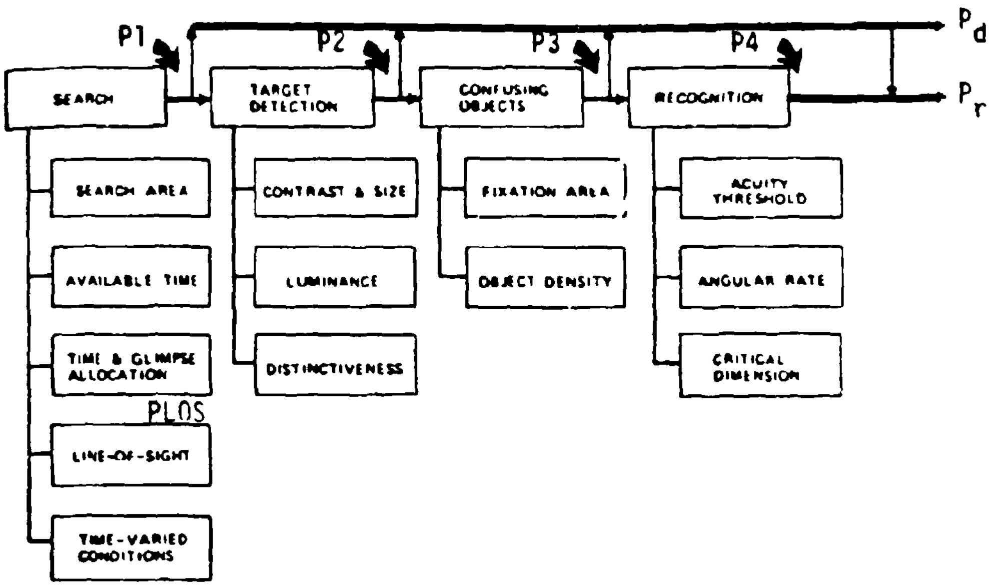
[4] Haugen, R., page 15.

3. Confusing objects, P3, involve the change of confusion between targets and non-targets. The fixation area and object density determines the degree of confusion.

4. Recognition, P4, involves the awareness that a detected object belongs to a particular class. Such elements as acuity threshold, angular rate, and the critical dimension of the object influences the probability that the target is recognized.

MODEL 2

MARSAM II - OBSERVER MODEL STRUCTURE



P_d = Probability of detection

PLOS = Probability of the existence of a line-of-sight to target

P1 = Probability of fixating and dwelling upon a target element

P2 = Probability of detectability

P3 = Probability of no confusion between target and non-target objects

P4 = Probability of recognizing a detected target

P_r = Conditional probability of detection and recognition

Model 2, therefore, clearly illustrates that once the observer (or sensing device) is within the specific search area, the target must be within line-of-sight of the visual system. When the target's contrast,

size, luminance, and distinctiveness is within certain limits, the probability of detectability will generally be within the limits of the visual system. In addition, this probability will further increase if the fixation area and the object density is within certain optical limits, such that the target will stand out from other objects within the area. Once the target detectability has been reached, the target is then recognized when the critical dimension stands out and the acuity threshold level and angular rate of the target are within detectable limits. The above description of Model 2 can further be illustrated by the following conditional probability of detection and recognition formulas:

$$\left.\begin{aligned} P_d &= PLOS * P1 * P2 * P3 \\ P_r &= P4 * P_d \end{aligned}\right\}^{5}$$

Once the target has been detected and recognized, the target can immediately be identified by type.

Target type characteristics play an important part in determining acquisition performance, whereby, a specific detail is used in the discrimination of the target itself. This specific detail generally stands out from the other target characteristics causing the observer's eyes to fixate on that particular element of detail. For example, in discriminating a bridge target from a building target involves a certain specific detail of each target which generally stands out. Differences in size, contrast, the presence or absence of shape details, cues, briefing information, and observer knowledge can attribute to the discrimination of the target type. Familiarity of the target has a major effect on target identification, particularly when a number of different targets are situated close together. If the same targets are grouped together, then identification is similar to the identification of a single target. On the other hand, if different targets are grouped together, then identification performance of the target of interest may be impaired; that is, the detection of the heterogeneous group of targets would be enhanced, but the observer would tend to fixate on one target within the group at the expense of other near by targets.

Another feature which enhances the probability of identification is target movement. Moving targets have been more easily acquired at lower altitudes (500 ft), or lower speeds (648.6 Km/Hr), than stationary targets. Erickson (ref [6], below), has pointed out three ways in which target movement may enhance the probability of detection:

1. A new target may be created by the motion, such as a dust cloud behind a vehicle;

2. Change in the location of the target due to its motion may be noted; and

3. The motion of the target may attract the observer's attention.

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[5] Greening, C. P., Mathematical Modeling of Air-to-Ground Target Acquisition, Human Factors. Volume 18 (2), pages 118-119. April 76.

Regarding the third item, the angular velocity due to the movement of the target over the ground must be discriminable from the apparent angular velocity of the ground at that point due to the aircraft's motion[6].

Other features of interest, such as, the target's context, the background of the target, the degree of target/background clutter, the degree the target is embedded within its surrounding area, and the terrain type will all influence the probability of identifying the target.

HUMAN OBSERVER SYSTEM

The probability of detection and recognition of a target in Model 2 is further dependent upon the limitational characteristics of the human visual system. In a real-time reconnaissance mission, the human visual system is the most important sensing device. Approximately 90 percent of all visual information extracted from the environment comes through the eye. The most important elements of the eye necessary in the target acquisition is the retina and fovea (shown in Figure 1). These two elements provide the sharpest and best color definition. When an object is viewed, the fovea of the eye is in direct line-of-sight of the object The visual detection process is the reception of the object's reflected light rays from the environment by the observer's eye. At times, these light rays are subject to absorption and scattering by fog, rain, or clouds, etc. For example, clouds will have two general effects upon target visibility:

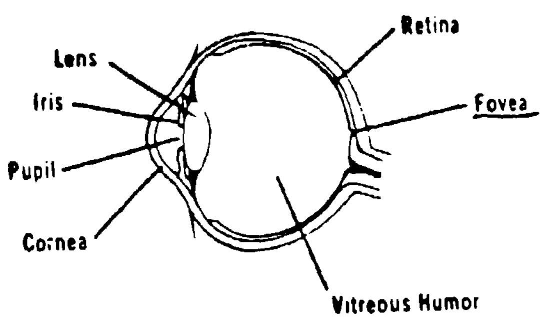

Figure 1. The Human Eye.

1. Obstruction of the target; and

2. Diffusion of the light coming from the sun, thus, affecting the way a target is illuminated.

The degree of light scattering results in a luminance path, thereby, reducing the target background contrast; and hence, making the target more difficult to find.

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[6] Marietta, M., pages 3.4-3.5

The sun's angle can also vary the amount of reflectance of a ground target; and depending upon the angle, will determine the probability of what the eye can see of the target. For example, as shown in Figure 2A, the amount of reflected light from a desert terrain for a given wavelength is dependent upon the sun's angle.

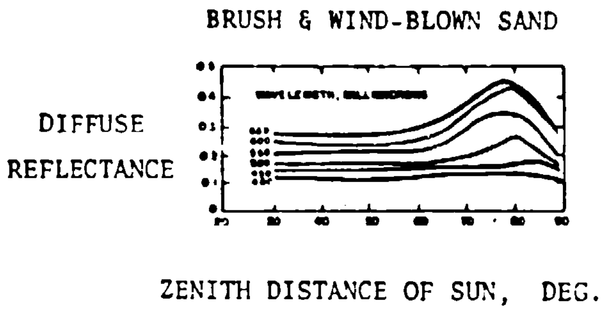

Figure 2A. The Amount of Diffuse Reflectance as a Function of Distance of Sun in Degrees for each Wavelength.

In addition to the above limitations of the eye, the color reflectance range of the human eye is between 400 to 700 millimicrons (Figure 2B). Conclusively, holding all the target variables constant, the environmental factors, the sun's angle, and the sensitivity of the eye has to be within certain limits in order for detection to occur[7].

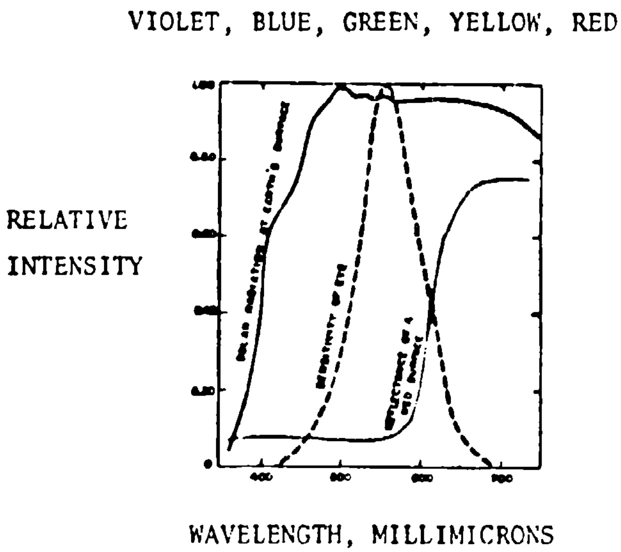

Figure 2B

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7 Boynton, R. M. et al., Laboratory Studies Pertaining to Visual Air Reconnaissance. WADC Technical Report 55-304, Part I, Wright Air Development Center, WPAFB, OH, pages 10-13, Sep 55. (Here and after refer to Boynton, R. M.).

Given that the previously discussed variables are held constant, some of the parameters in Model 2, which will influence target acquisition, will be briefly discussed:

1. Target size and shape;
2. Contrast of target to background;
3. Speed of the aircraft (exposure time);
4. Object density; and
5. Scale factor and display size (search area).

The following discussion will also include some supportive experimental data of man's visual system limitations during target acquisition.

Target shape has been found to influence the observer's probability of detection and recognition. The perception of a critical target can be complicated by the fact that the observer might think he sees something, but be uncertain to its particular shape or configuration. Figures 3 through 9 provide the percent correct response performance as a function of the subject to target display distance (STD), in feet, of the following groups of forms:

1. Rectilinear forms of such shapes having straight edges and sharp corners: pentagon, triangle, quadrangle, and cross;

2. Nothingon forms having a multisided shape;

3. Struniforms having a curvilinear shape; and

4. Y-shaped figures.

The contrast of these figures was also varied from a 100 percent contrast to a seven percent contrast. The data illustrates the following:

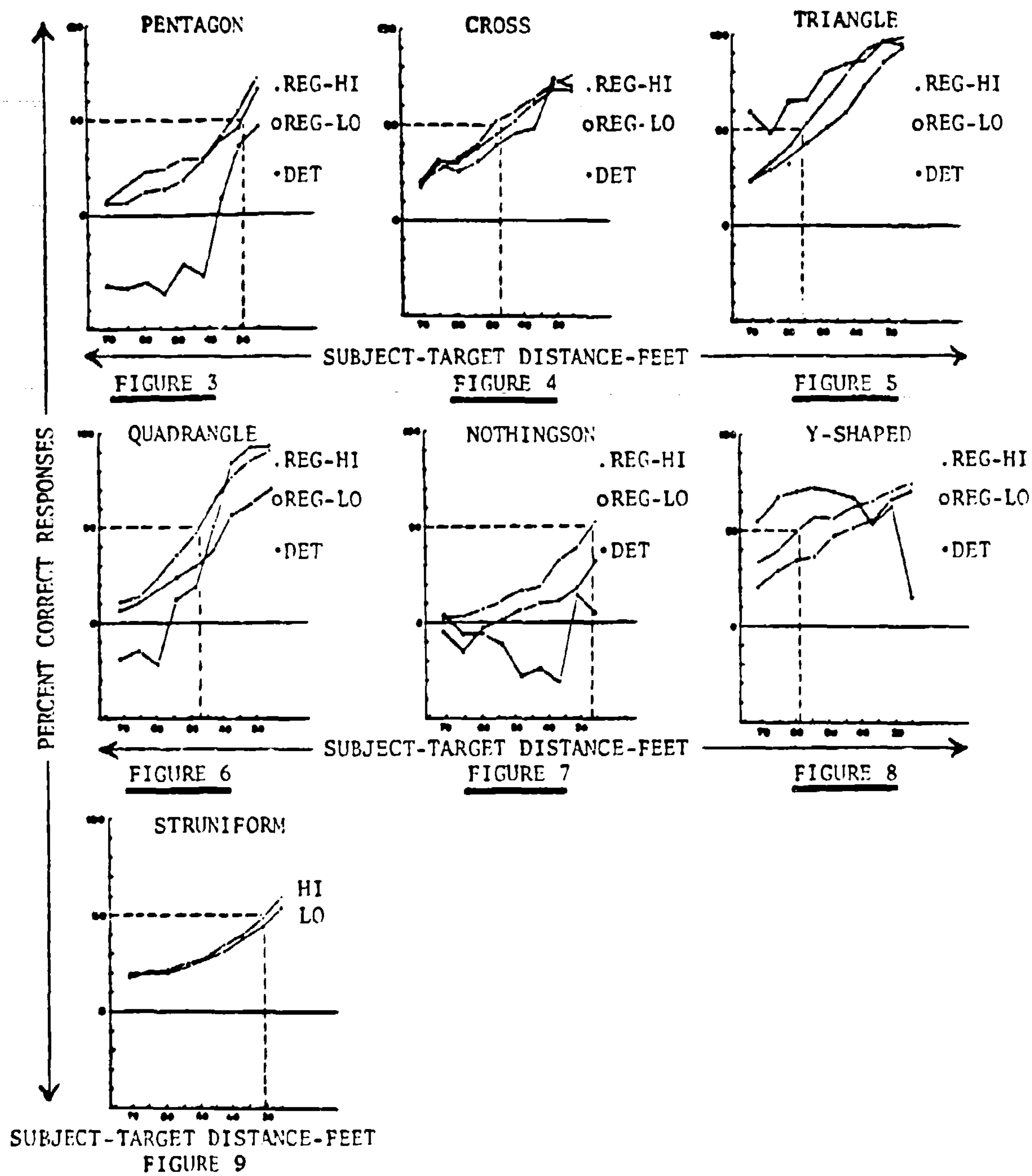
1. Once the target was recognized, there was not much difference found in the number of responses when the contrast was varied from 100 percent to seven percent;

2. The triangles and quadrangles resulted in higher detection and recognition responses, especially, at the farther STD while the nothingons displayed the lower responses at the closer STD; and

3. Detection and recognition performance also increased as the STD decreased for all figures[8].

Also found in the above experiment, was that a contrast reduction from 100 percent to seven percent is nearly compensated for by an increase in figure size from six linear units to 10 linear units. Exposure time of the target to the observer is highly important in detecting

[8] Boynton, R. M., Part I, page 22.



Figures 3 - 9. For each Form, the Percent Correct Recognition as a Function of Subject-Target Distance. Hi Contrast versus Low Contrast Shown for Recognition.

the target. As shown in Figure 10, the exposure times of 3, 6, 12 and 24 seconds illustrate that percent of recognition increases as a function of a decrease in STD when the exposure times are increased.

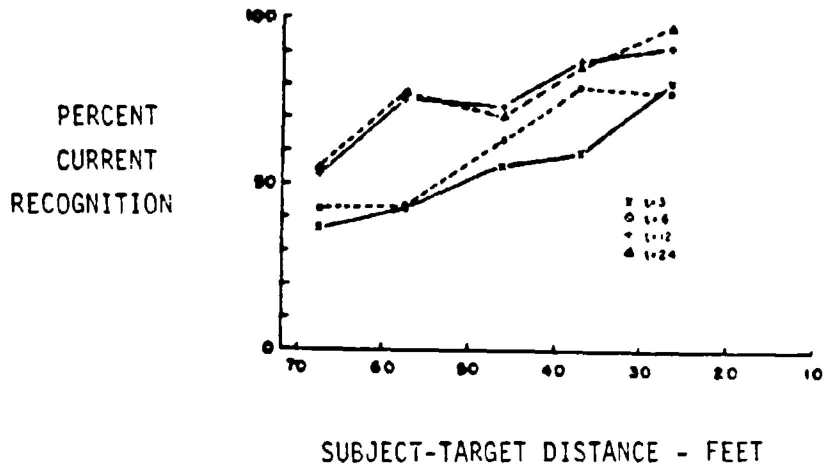


Figure 10. Percent Correct Recognition as a Function of Subject-Target Distance for Each Exposure Time (+).

Also of importance, as previously shown in Model 2, is the object density. As the target area becomes more complex with other confusing forms, the observer's recognition performance decreases. It is shown in Figure 11, as the display figures are increased from 16, 32, to 64, the recognition performance data decreases. In addition, if the STD decreases, the recognition performance increases with all the numbers of figures[9].

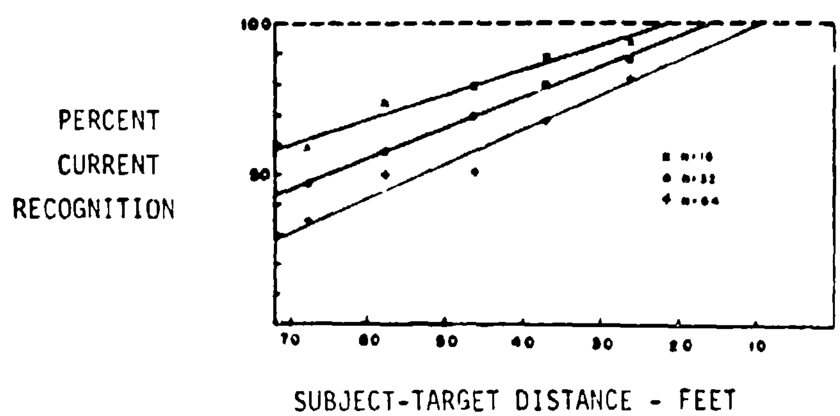


Figure 11. Percent Correct Recognition as a Function of Subject-Target Distance for the Number (N) of Figures.

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[9] Boynton, R. M., Part I, page 22.

Figures 12 and 13 illustrate what happens when you simultaneously have an increase in the number of figures and a decrease in exposure time. As illustrated in the Figures, there is not very much improvement in recognition under any condition when exposure time is increased from 12 to 24 seconds; therefore, efficient processing of information may not occur during the second half of a 24 second exposure[7].

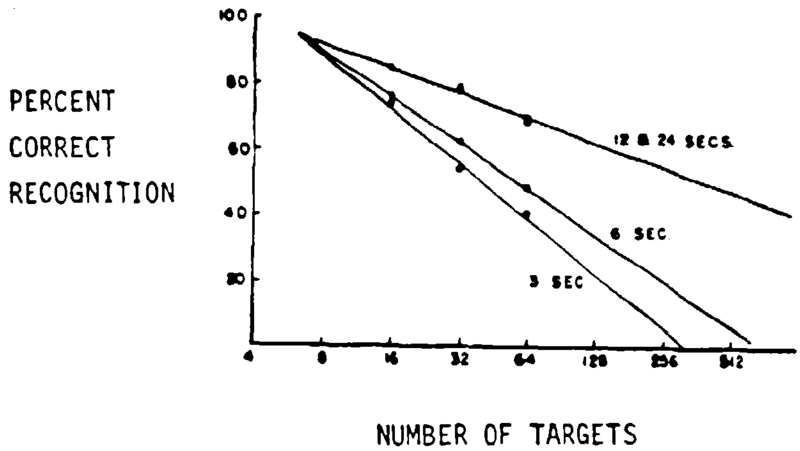

Figure 12. Percent Correct Recognition as a Function of the Number of Targets for Each Exposure Time.

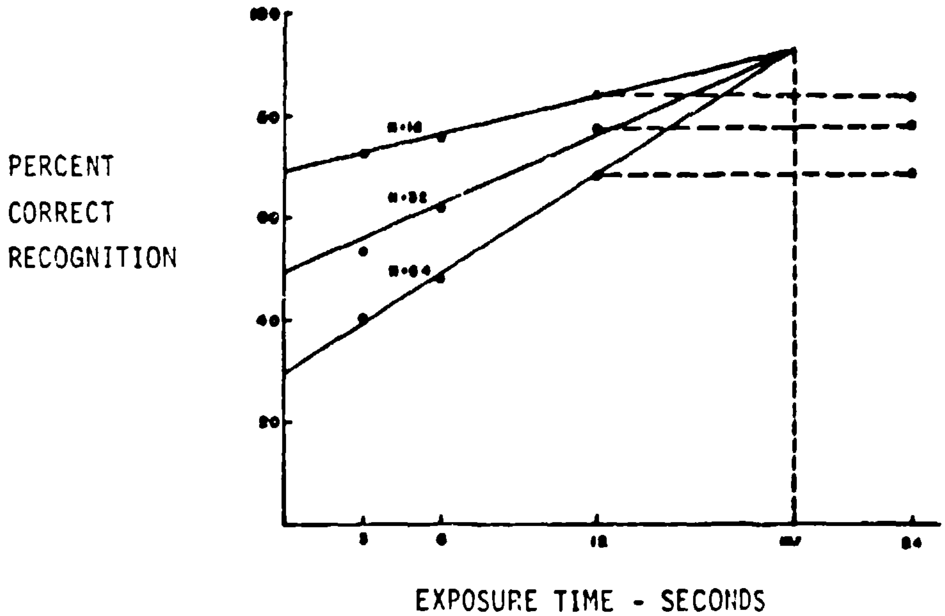

Figure 13. Percent Correct Recognition as a Function of the Exposure Time for the Number of Figures.

Figure 14 illustrates, in addition, the importance of target size, as well as, exposure time in recognition performance. From observations of the figure, a figure size of two units will produce the highest percent recognition performance for all exposure times, in addition to an exposure time of 12 seconds at the closer simulated distances.[10]

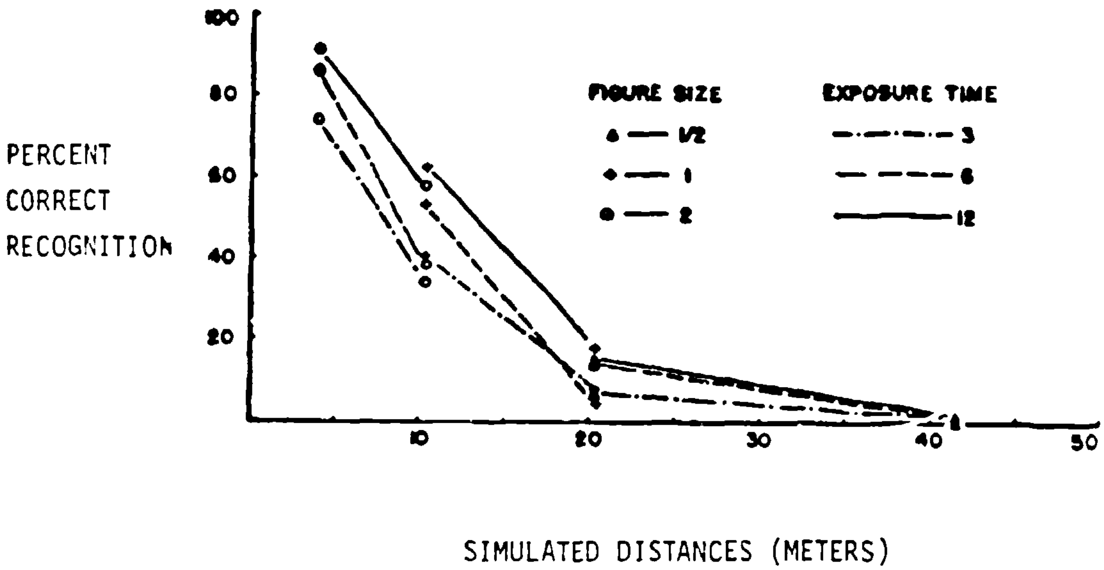

Figure 14. Mean Percent Correct Recognition as a Function of Simulated Distances for Both Figure Size and Exposure Time.

As mentioned previously in Model 2, contrast has an impact on the probability of detection and recognition. Figure 15 illustrates that there is not very much difference in performance between 100 percent contrast to 44 percent contrast as a function of STD, but there is a significant difference found for the 18 percent contrast[11]. Figure 16 shows that for 100 percent detection to occur by the observer, the actual target/background contrast should be about twice the observer's threshold contrast[12]. From observation of measurements of prior contrast models, it has been found that olive drab troops and vehicles in a California desert have a contrast of about 60 percent, but olive drab troops and vehicles on a black pavement, some dirt roads and green grassy fields have a lower contrast of about 30 percent; thereby, reducing the probability of recognition[13].

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[10] Boynton, R. M., Part II, pages 8-9.

[11] Boynton, R. M., Part II, page 11.

[12] Erikson, R. A., Visual Detection of Targets: Analysis and Review. AD 612 721. US Naval Ordnance Test Station, China Lake, CA. Feb 65. Pages 25-26.

[13] Erikson, R. A., page 21.

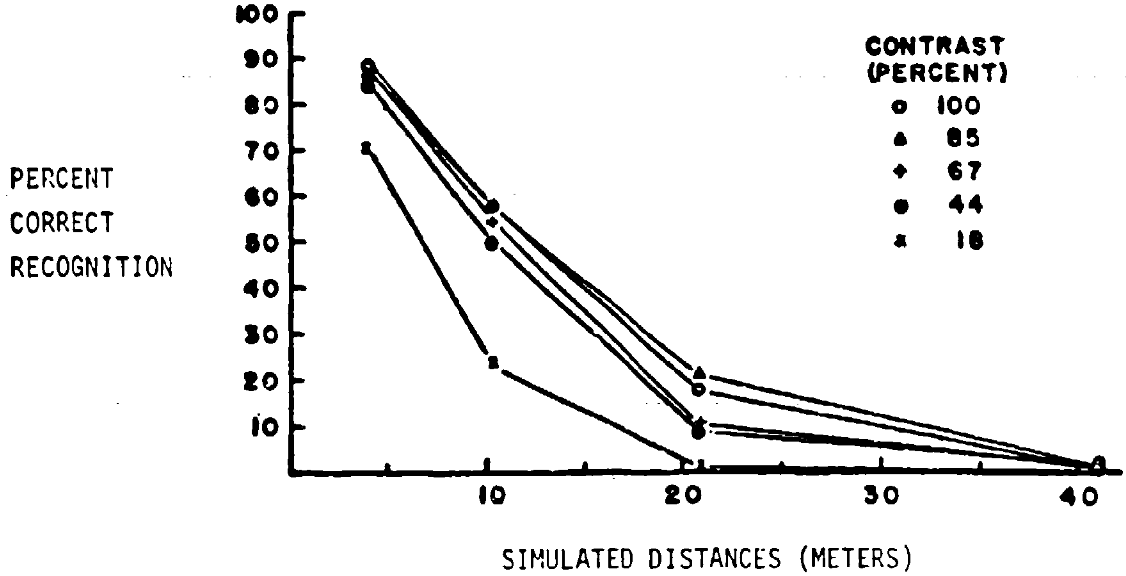

Figure 15. Mean Percent Correct Recognition as a Function of Simulated Distance for Each Contrast.

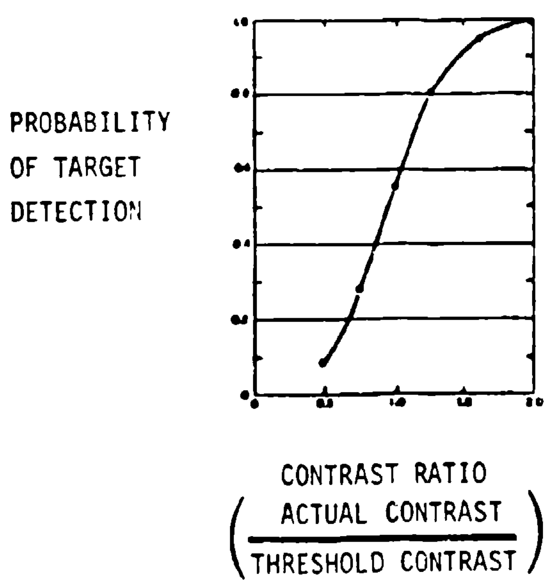

Figure 16. Probability of Target Detection Using Rectangular Targets on a White Background as a Function of the Contrast Ratio.

It can be concluded at this point, that the target acquisition process is dependent upon several variables of the human visual system. First, there has to be a trade-off between the size and contrast of targets in order for recognition to occur. A contrast reduction of from 100 percent to 67 percent contrast can be compensated for by an increase in figure size from six to ten linear units. For approximately 50 percent correct target acquisition, there should be a minimum of approximately 50 percent contrast, at an exposure time of 12 seconds at a minimum figure size of one unit, and a maximum of 16 targets at a maximum simulated distance of 15 meters. Although we have cited many limitations of the human visible system during the target acquisition phase, it has been found to be the best method for fast reporting to units capable of attacking fleeting targets.

AIDED SENSOR DEVICES

Since the human visual system is limited when the mission requirements are held under the constraint of the variables previously discussed, and under all weather and nighttime capability rules, sensing device aides may be necessary to increase the human visual system capabilities. Image devices, such as radar and infrared, are very beneficial to the observer during periods of poor visibility; and for this reason, were invented to extend beyond the visible region of the human visual spectrum (shown in Figure 2).

Image devices may be indicated by scope presentation for instantaneous viewing, photographic recording for detailed study, and reuse and/or transmission to a ground station. Each type of sensing device produces a different distribution of signal strength on the display for the same objects and backgrounds. The pilot utilizes the images produced by the signal in indicating the target position once he has established that it is the target of interest. The target signals produced by infrared or radar devices may be displayed on the scope as real images, vague images, or symbolic images which may bear no resemblance to the real targets of interest. In order to better identify the activity, displayed information of movement must also be supplemented with visual observation, radar, and TV.

Aerial photography and TV are other devices utilized in target and terrain information gathering. The images displayed by these methods generally appear more real to the target of interest.

RADAR

Radar systems are generally used for the detection of distant objects via the reflection of radio waves. During a reconnaissance mission, a radar transmitter sends a beam (pulse) of energy in a given direction. Objects in the path of the beam scatter the incident radio energy, reflecting some of it back to the radar antenna. The energy that is returned is detected by a radar receiver and the returned signal is

displayed on a cathode ray tube indicator. If targets of interest are obscured by hills or vertical objects, these targets will neither receive nor return the microwave pulses to the receiver as a result of radar waves traveling in straight lines. The radar generates images that record the reflective properties of the terrain at microwave lengths between 1 cm and 30 cm. These microwaves are 100,000 times longer than the waves of visible light. Therefore, the microwaves of certain frequencies are little affected by the atmospheric conditions and weather conditions which provide a good supplement to the pilot's visual system during target acquisition.

Radar systems are classified into three types: active, passive, or semiactive. Active systems contain both a transmitter and receiver. Passive systems, on the other hand, are for countermeasure use. In this system, a radar transmitter is not used; and instead, the radar receiver picks up the transmitted energy from other radar transmitters. In general, a scanning system is utilized so that the receiver is constantly scanning the frequency bands of interest. The semiactive system employs an isolated receiver with a cooperative transmitter.

In presenting target information to the observer, a radar strip mapping application is used. A side-looking radar presents target information at ranges perpendicular to the line-of-flight. The range information is shown as a single scan line on a cathode ray tube, and is photographed by a moving film system. The film speed is proportional to the aircraft speed. In this manner, each sweep of the CRT is written on the film slightly displaced from its predecessor, and a complete radar map of the area is built up. This type of system may make a map covering 20 or 30 NM in width[14].

As the radar maps the ground during a target search, it is the observer's task to find the prebriefed target as quickly as possible. Once the target is found, it is initially designated on the screen (in passing scene mode or sequential snapshot mode), causing an expanded view of the target region to be displayed. An aimpoint on the target is then designated as precisely as possible (by placing cross hairs over the target) in order to provide guidance information to the weapon system. In providing the operator an excellent chance of finding the target, there are several key factors which should be performed:

1. Provide the operator with prebriefing information on the target and background cues;

2. Provide adequate reference material to the operator for map-matching; and

3. Provide the operator with the background complexity information of the target area so that the pilot can adjust the radar coverage accordingly[15].

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[14] Poole, H., Fundamentals of Display Systems. Pages 211-217. Macmillan and Company, Ltd., London. (Here and after refer to Poole, H.).

[15] Carel, W. L. & Hershberger, M., Operator Performance in Real-Time Target Acquisition, Report No. P67-146, Hughes Aircraft Company, Culver City, CA. Jul 67. Pages 4-70 - 4-71. (Here and after cited as Carel).

In reference to the above key elements, it was found through experimental analysis, that the type of reference material used during map-matching has an impact on the time it takes to identify the target. The following reference type materials were compared:

1. Radar map-target and area taken directly with APQ-97 real array radar imagery;

2. Photographic maps - slides of vertical, aerial pictures; and

3. Charts - slides prepared from geological survey topographic maps at a coverage of: (a) 2.5 NM, and (b) 7.5 NM.

The radar reference material was shown to be the best for both recognition and target acquisition times (Figure 17). This was probably due to the radar reference material being identical to the imagery on the prime radar display (the map-matching technique). The photographic reference material

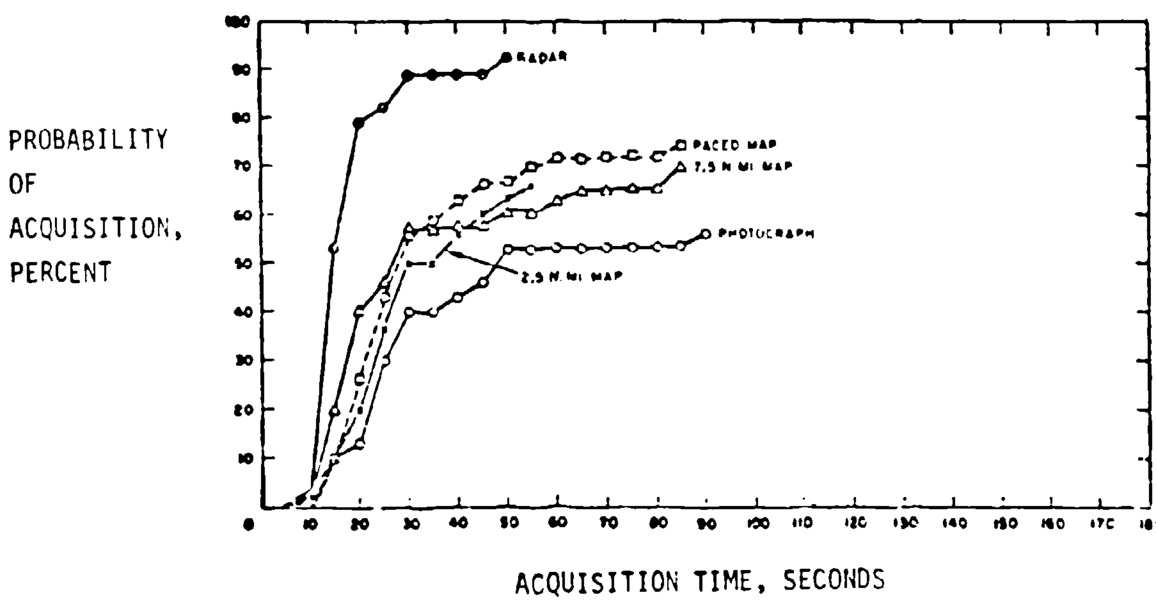

Figure 17. Persent Probability of Acquisition as a Function of Acquisition Time for Each Reference Map.

produced the poorest performance, probably due to the resolution in the photograph was an order of magnitude better resulting in more detail shown to the observer. The observer, therefore, had to filter out much of this detail when attempting to correlate this photograph with the real displayed radar image. In addition, things that showed up white on the photograph showed up white, gray, or black on a radar imagery producing a difference in brightness relations and causing the observer to transform additional information.

Figure 18 also illustrates that target designation time performance was higher for the one and two NM coverage because it provided the operator a sufficient amount of displayed information.

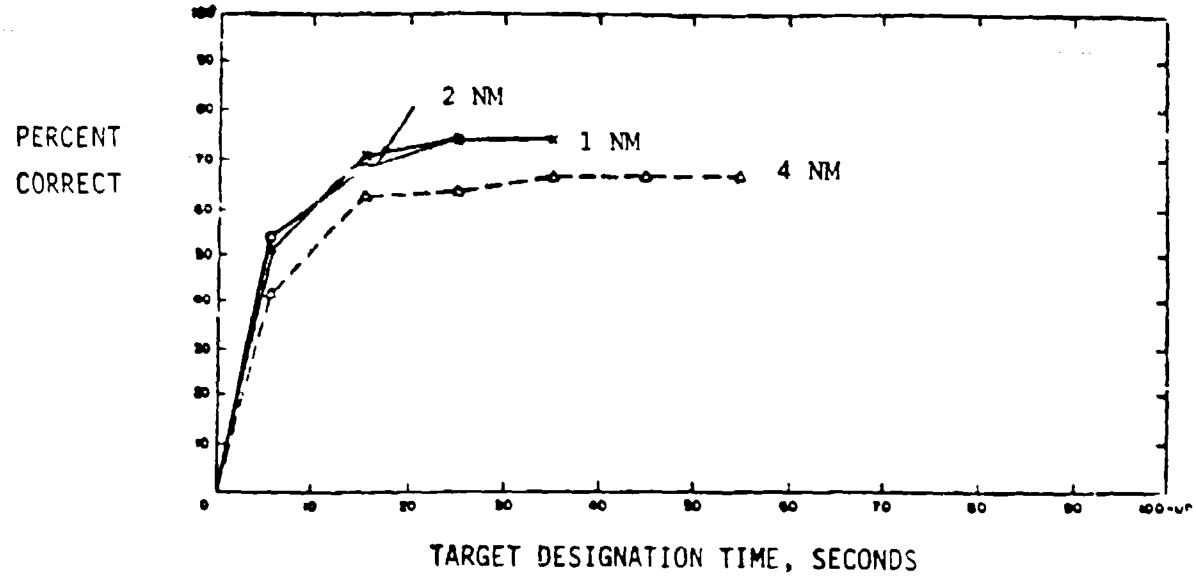

Figure 18. Percent Correct Performance as a Function of Target Acquisition Time for each Ground Coverage.

In addition, it was also found that target size did not have a significant effect (5-10 percent effect accounted for) on all measures of target performance, but the background cues exemplified a greater effect on target detection. Target type, illustrated in Figure 19, also produced significant effects on radar target acquisition performance[16].

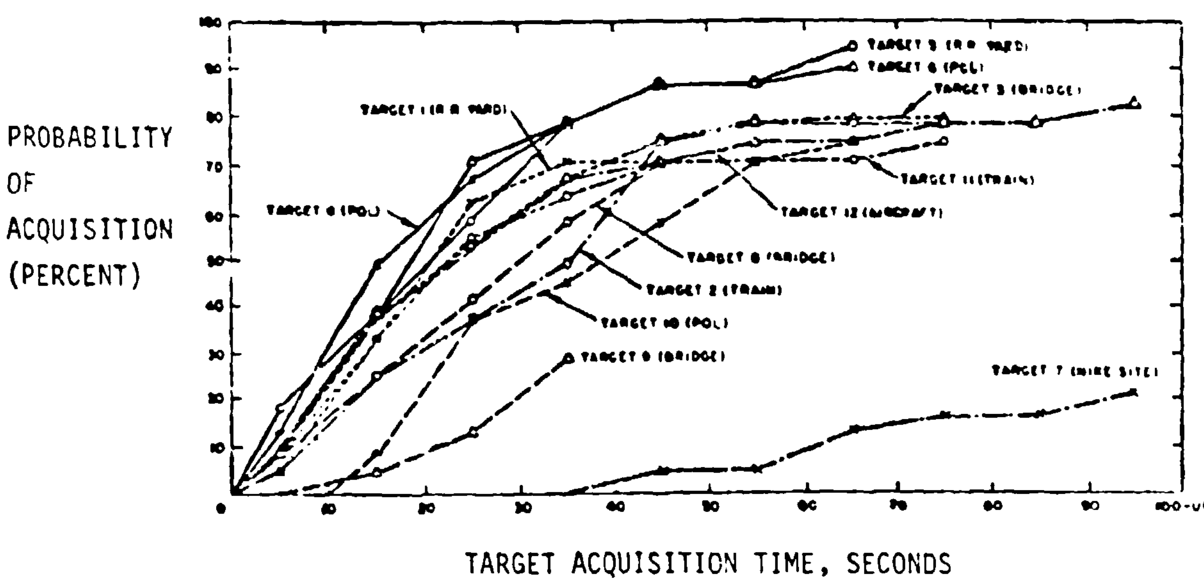

Figure 19. Percent Probability of Acquisition as a Function of Target Acquisition Time for Each Target Type.

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[16] Carel, W., pages 4.10-4.18

INFRARED

Infrared (IR) devices, on the other hand, are valuable in penetrating camouflages and collecting information at night. Infrared detects hot objects out to about 30 miles indicating traveled routes, vehicles, weapons, and similar activities and installations.

IR systems are primarily of a passive nature. The few active systems have very limited range. This is due to the difficulty of making an IR source with limited beam width and to the IR absorption of the atmosphere. Range determination of a target is possible by triangulation or by knowledge of altitude. The triangulation method employs two sets of IR detectors, spaced a known distance apart. The difference in azimuth and elevation angles allows range to be computed. Range to a ground target can be computed by knowing altitude, azimuth, and elevation angles.

Since the system is passive, wavelengths from a wide spectrum of IR are received. By having three detectors, each sensitive to three parts of the spectrum, an IR color pattern of an object can be obtained. This can be presented on a multicolor tube, giving the observer added information about the target. Alternately, the information can be used to presort targets so that only targets with particular wavelength characteristics are presented[17].

According to previous studies with infrared image variables effecting human performance, the optimum altitude for accuracy of 50 percent and better of sparse tactical targets is 500 to 1000 feet, shown in Figure 20 when the following conditions are met:

1. When mapping sensors with field-of-view, resolution, sensitivity, etc., similar to the AAS-10 infrared set are used;

2. When there is a high probability that the targets will be in the field-of-view; and

3. When the sensor aircraft travels about 170 knots ground speed or slower.

Regarding target types, Figure 21 also illustrates that boats and bridges produced the highest percent performance of targets identified at the 500 feet altitude. The bridges also produced a high percent identification performance at the 2000 feet altitude illustrating that target type can influence target identification times with infrared devices[18].

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[17] Poole, H., pages 224-226.

[18] Maher, F. and Porterfield, J. L., Target Detection and Identification Performance on Infrared Imagery Collected at Different Altitudes, AMRL-TR-70-127, Aerospace Medical Research Laboratory, WPAFB, OH.

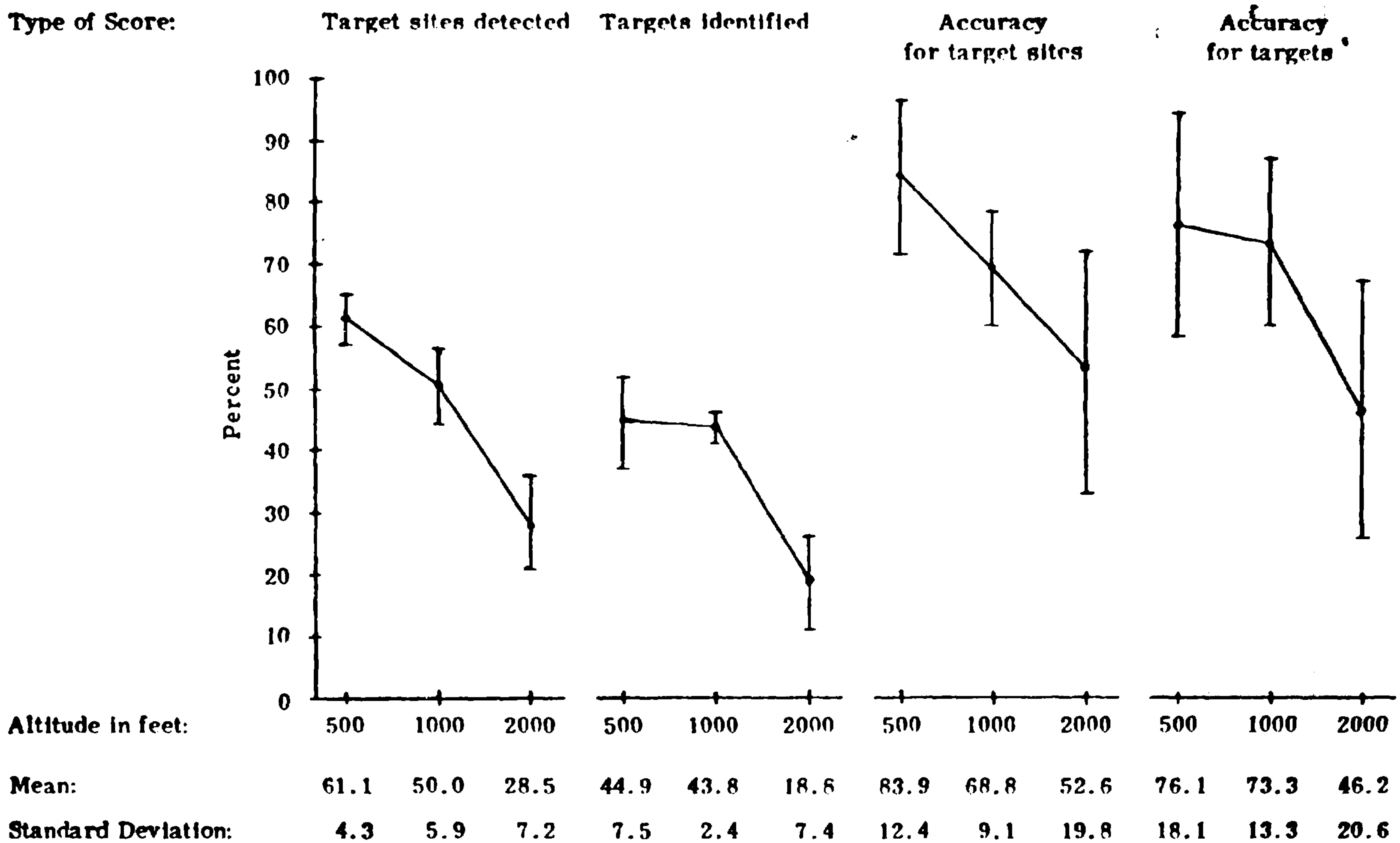
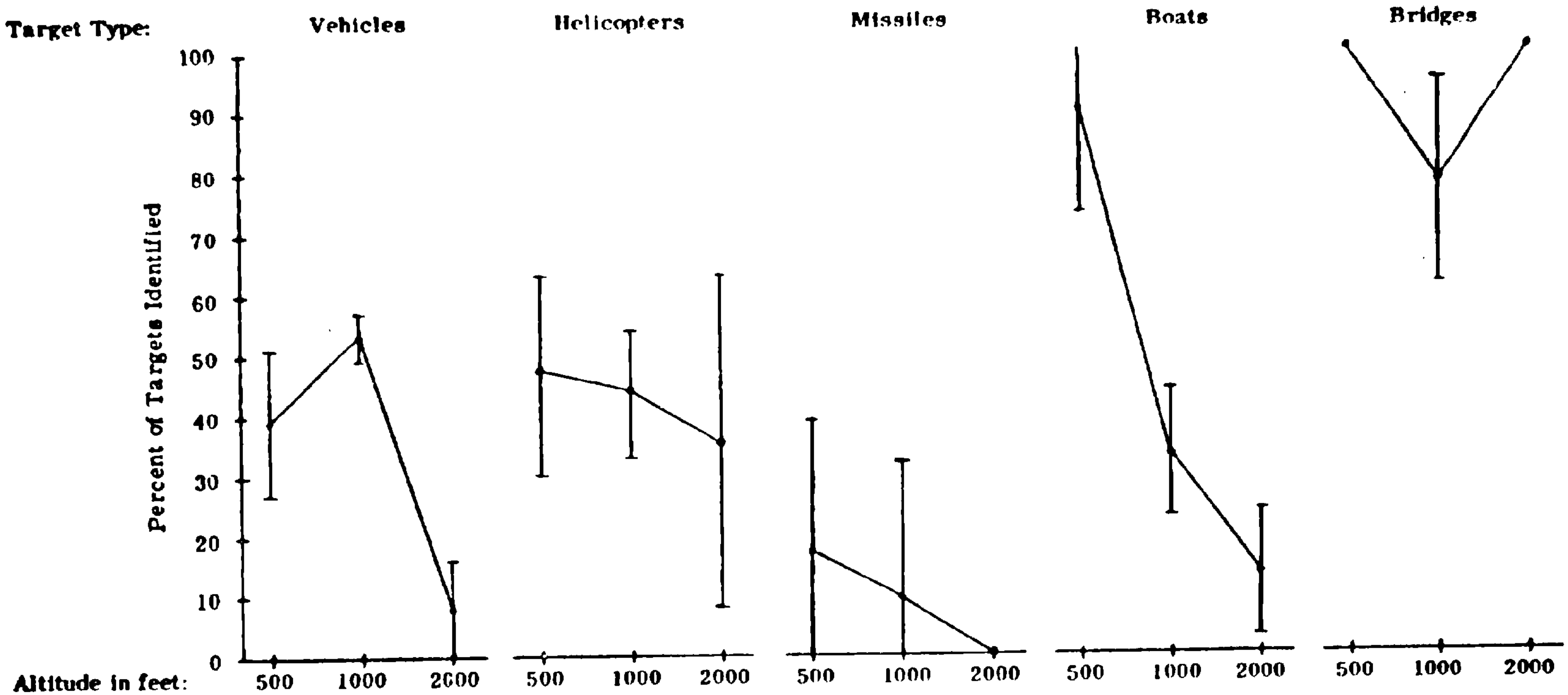


Figure 20. Percent Performance Across Altitudes.



Target Type:	Vehicles			Helicopters			Missiles			Boats			Bridges		
Altitude in feet:	500	1000	2000	500	1000	2000	500	1000	2000	500	1000	2000	500	1000	2000
Mean:	39.1	52.9	8.0	46.9	43.8	35.4	16.7	9.3	0.0	90.0	36.3	13.3	100.0	77.8	100.0
Standard Deviation:	12.3	4.2	8.1	16.7	10.5	27.9	21.9	22.7	0.0	16.7	10.3	10.3	0.0	17.2	0.0

Figure 21. Percent of Each Type of Target Identified Across Altitudes.

PHOTOGRAPHY AND TV

Aerial photography and TV are other sensing devices utilized in target and terrain information gathering. Both types are used in obtaining detailed information of larger areas. Both types can be presented to the air pilot, as well as, the photograph interpreters in the ground-based stations. Air photographs are generally processed and analyzed by good interpreters on ground-based stations when more accurate detailed information is needed. The photograph interpreters can detect enemy camouflage better than the observer in the aircraft. There is a great disadvantage of aerial photography when it is time for film processing, interpreting prints, and disseminating the information into the picture.

The TV method, functioning within the visible portion of the electromagnetic spectrum, can be shown on a CRT or heads-up display, either to the aircraft observer, or can be displayed to photograph interpreters in the ground-based stations. This method also provides a more accurate means of displaying detailed information to the aerial observer or photo-interpreter.

In viewing the picture by the observer, the key element of TV processing is the frame rate. According to experimental analysis, there is no real reduction in the number of targets required when the frame rates are reduced from 24 image frames/second to one frame/second; but it was found that target types had an effect on target detection at various frames/second. Therefore, the likelihood that a target will be acquired is greater for targets that are acquired at longer ranges; easier targets tend to be acquired at longer ranges.

According to a McDonnell-Douglas research program, when comparing the infrared versus the TV sensing devices, the infrared targets were detected more quickly and at greater stand-off slant ranges than TV targets, especially, when targets were embedded in background scenes of medium to high background complexity and especially for hot targets during detection and recognition processes. Data was collected for the 5000, 15,000, and 30,000 feet slant ranges at a 5000 feet altitude on a clear day. Figures 22 through 25 clearly illustrate that for the active (hot) target, the forward-looking infrared provides the lowest target detection times at the longest slant range of 30,000 feet as a function of scene complexity for both target detection and target recognition; and, response times were also shorter for active target FLIR signatures than for inactive target FLIR signatures which, in turn, were shorter than for TV target signatures. Luminance distributions within the different targets were found to serve as an important cue for recognition for IR than for TV targets, as well as, target background contrast[19].

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[19] Beideman, L., Gomer, F. E., Levine, S. H.; Dynamic Target Acquisition: Empirical Models of Operator Performance. McDonnell-Douglas Astronautics Company, St. Louis, MO.

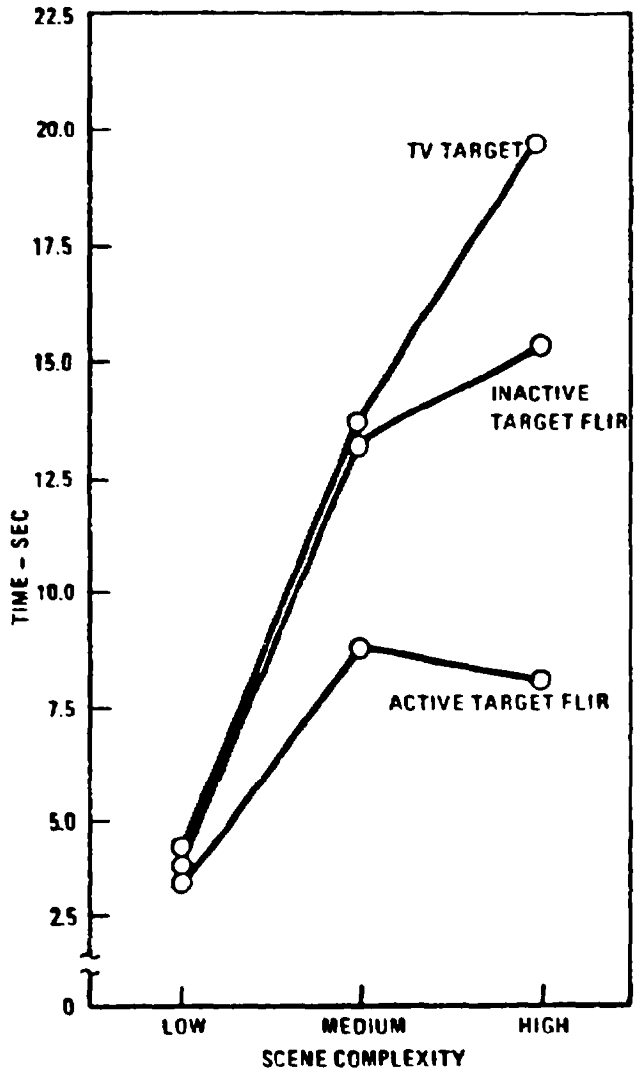

Figure 22. Response Time to Target Detection - Signature X Scene Complexity Interaction (30,000 Ft Initial Slant Range).

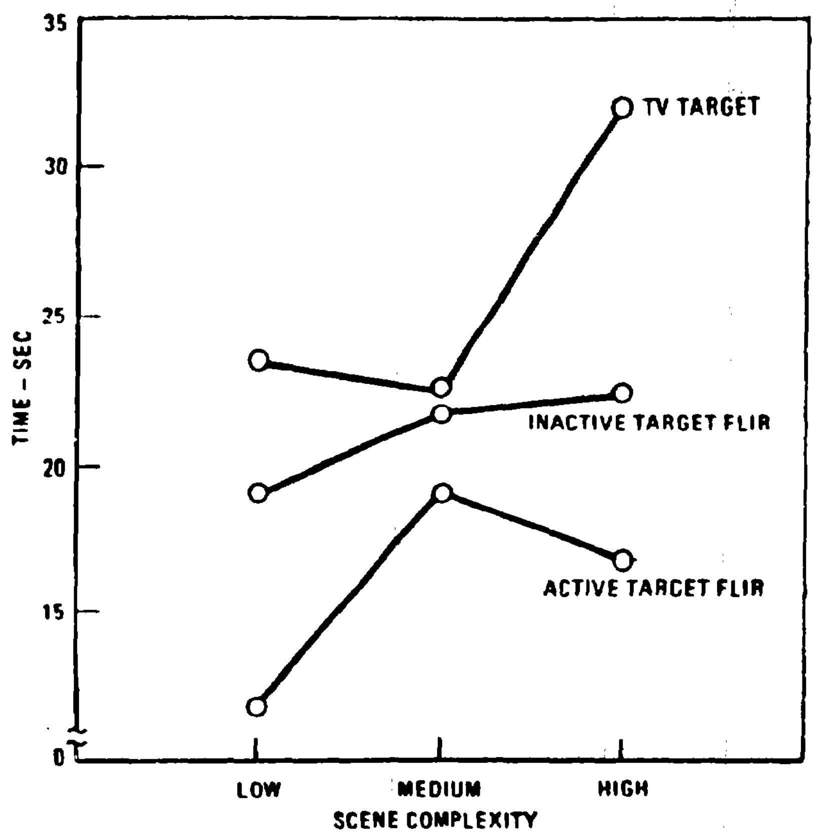

Figure 23. Response Time to Target Recognition - Signature X Scene Complexity Interaction (30,000 Ft Initial Slant Range).

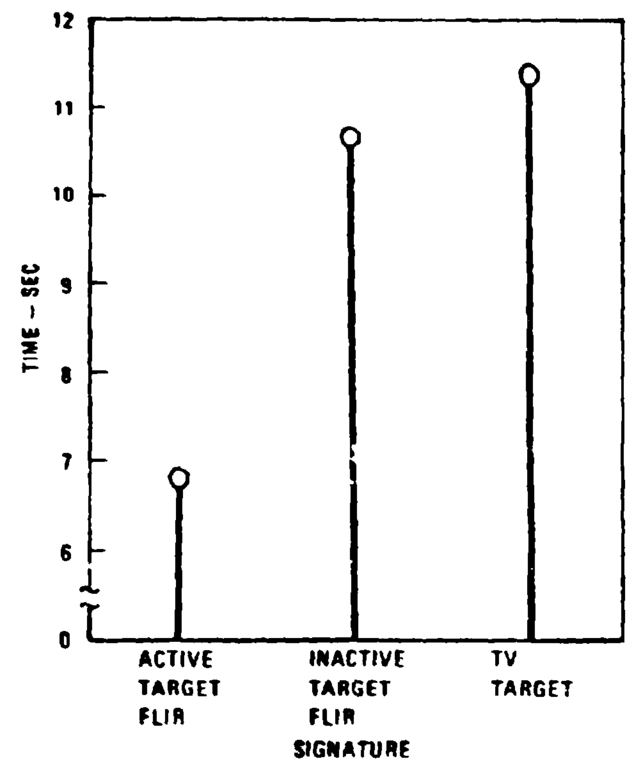

Figure 24. Response Time to Target Detection - Signature (30,000 Ft Initial Slant Range).

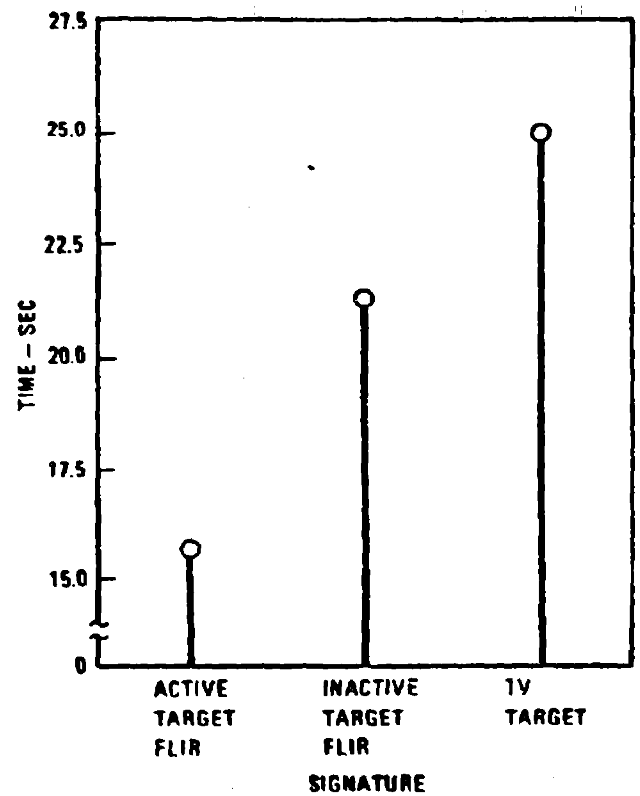

Figure 25. Response Time to Target Recognition - Signature (30,000 Ft Initial Slant Range).

ENABLING VARIABLES OF DISPLAY

All of the devices previously discussed, utilize a display in presenting the signal information to the observer. In addition to the elements in Model 2 which are necessary in the target identification by the observer, there are also additional variables necessary in increasing the probability of detection and recognition of the target image once it has been displayed on the screen. The enabling variables are beneficial to the observer in determining whether or not the target image appears on the display in recognizable form assuming that the target is in the field-of-view of the optical sensor. The three enabling variables are: resolution, scale factor, and contrast.

In order for the image of an object on the ground to be identified by its shape or appearance, the sensing and display system must have a resolution appropriate to the size of the significant details in the object. Resolution will be the smallest distance between two equal point reflectors that can be discarded as separate.

The scale factor is the ratio of a measure of a linear dimension of an object on the display to the equivalent measure of the corresponding object on the ground. Figure 26 illustrates that as the largest target size dimension increases, the display size should also increase, given a certain amount of ground coverage. The display size can be calculated in inches according to the following formula:

$$\frac{\text{GROUND RANGE}}{\text{TARGET SIZE}} \times .042 = \text{DISPLAY SIZE (INCHES)}$$

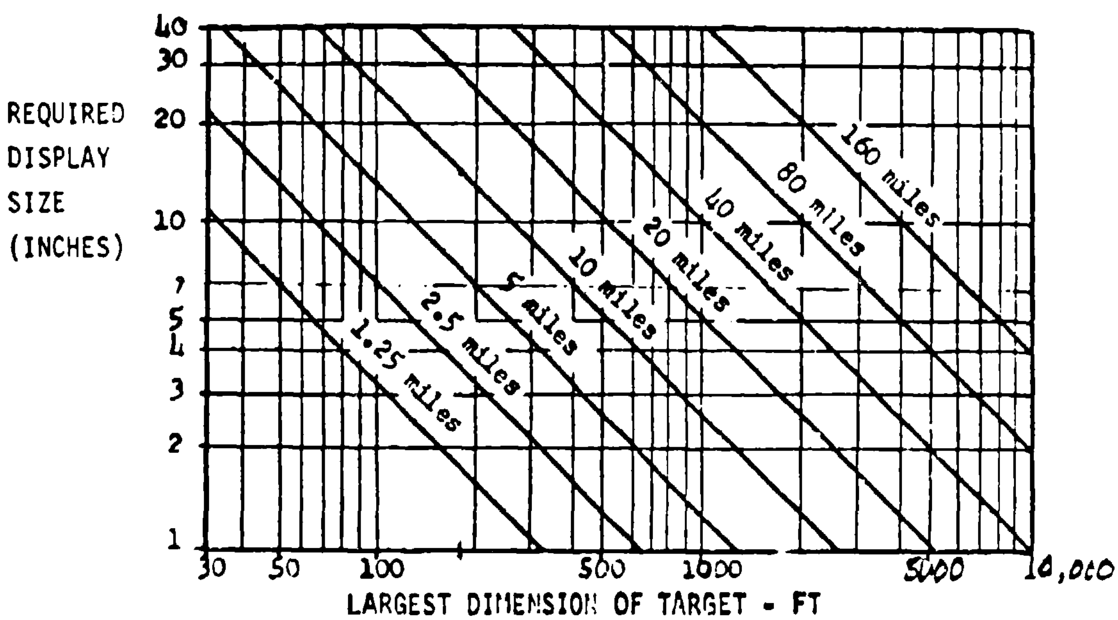

Figure 26. Required Display Size (inches) as a Function of Target Size for Various Ground Ranges Displayed to the Observer.

where:

0.42 inches is the minimum size a target must have in order to expect relatively accurate and rapid recognition

Therefore, if a critical target has a length of 50 feet, and the display size is fixed at 10 inches, the ground range displayed cannot exceed 2.1 miles according to Figure 26. A larger display increases the search time of the operator. If a time limit is imposed on identification by the speed of the aircraft, some compromise must be reached between the size of the object to be identified and the amount of ground coverage to be displayed; or additional displays and operators must be employed. In addition, if the target location is known, then the ground coverage need only be sufficiently large to compensate for errors in navigation. If the location is only approximately known, increased ground coverage has obvious advantages. If the target location is unknown, then increased ground coverage improves the probability that a target of opportunity will appear within a given time. These relationships are further complicated by the fact that the display is two dimensional; whereas, aircraft movement and, hence, the time limitation upon identification are associated with only one of these dimensions. If the ground image, therefore, moves across the display as the aircraft flies over the ground (in the range dimension), there exists some maximum aircraft speed beyond which a single observer will no longer be able to search all of the ground image[20].

In addition, the contrast between target and background has to be sufficient to allow for detection as pointed out earlier in Model 2.

In illustrating the importance of the above enabling variables, the following data shown in Figure 27 was found in acquiring radar targets:

1. For a displayed radar ground coverage less than or equal to approximately five NM and a 50 feet resolution, the size of the radar display has little effect on the time or probability with which an operator can detect targets;

2. For displayed scale factors between 1:15,000 and 1:60,000, a smaller six-inch display results in shorter acquisition times than the 12-inch display; and

3. Target acquisition time and probability of recognition improve as the scale factors of the displayed radar imagery increases or as the ground coverage decreases.

According to this study of Figure 27, the best target acquisition performance for 1.25 NM, was a six-inch display at a scale factor of 1:15,000[21].

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[20] Baker, C. and Steedman, W. C.; Target Size and Visual Recognition. WADD Technical Report 60-B, Wright Air Development Division, WPAFB, OH, February 1960, pages 13-15.

[21] Carel, W., pages 4.60-4.62.

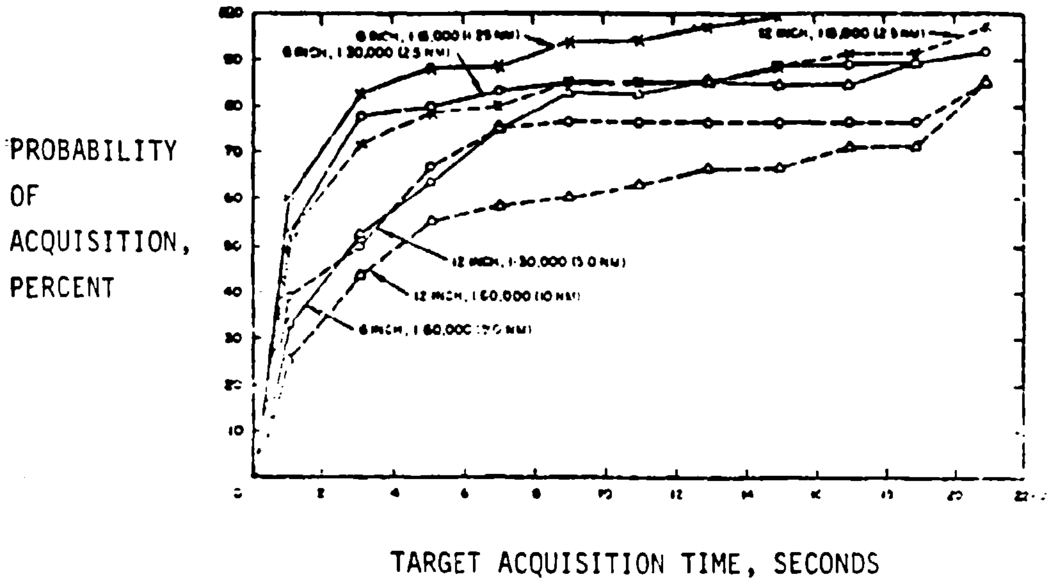

Figure 27. Percent Probability of Acquisition as a Function of Acquisition Time for Display Size and Display Scale Combination.

Resolution and scale factor variables also effect identification in aerial photographs. When identification is made on the basis of gross visual cues or contextual cues, such as the comparison of the textures of different sections in a city or locations near a railroad or airfield, an enlargement in scale results in a loss of the cues. On the other hand, when identification depends upon discriminating small details that are hard for the eye to discern or when the texture of very small details must be perceived, an enlargement of the scale is beneficial. Simultaneously, for scale enlargement to improve identification, the resolution must be sufficient to permit for these fine discriminations. At a scale of 1:40,000 objects, such as trucks, run-up stands and automobile parking lots cannot be identified; but at 1:27,000, the larger parking lots and larger run-up stands can be identified. At 1:12,000, the smaller run-up stands can be identified and whether or not they have aircraft can often be determined. Also, isolated trucks are identifiable at this larger scale. At the smaller scales, functions of complex targets are more difficult to determine[22].

Orientation of the target scene is another variable which will affect perceptual performance. Display orientation has been found to be better in the horizontal dimension than in the vertical dimension due to the spatial characteristics of the two eyes.

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[22] Haugen, R., pages 22-49.

AIRCRAFT VARIABLES

The last variable in the target acquisition Model 1, which will be briefly discussed, is the aircraft. In order to maximize target acquisition performance, the following aircraft elements are of influential importance:

1. Speed of the aircraft;
2. Motion of the aircraft in relation to the target;
3. Altitude of the aircraft;
4. Vibration of the aircraft; and
5. Type of aircraft.

The speed of the aircraft is confounded with the time and altitude variables. As the aircraft speed is increased, the less time there is to search the ground and/or display for the target. At speeds of 649 to 1334 km/hr, at altitudes of 200 to 1500 feet, US Air Force tests of target search report no significant problems in detecting targets (Thackham, Wade, and Clay, 1966). For lower speeds of 74 to 185.3 km/hr at a lower altitude of 500 feet, tests of the US Army fixed-wing and helicopter aircraft indicate a small decrement in target acquisition (Blakeslee, 1963; Thomas, 1965).

AIRCRAFT MOTION

Aircraft motion involves three types of movement during an air-to-ground target search:

1. Movement of the observer through a relative static environment;

2. Movement of the target relative to the environment and the observer; and

3. Movement of the background and the target relative to the observer as viewed on a display screen.

Increasing the altitude affects the visual environment to facilitate finding targets in some cases, but can also reduce finding targets in other cases. An increase in altitude may:

1. Increase the amount of terrain that can be seen, thus increasing the possible cues available;

2. Reduce the effects of masking;

3. Change in apparent size and shape of the target as a result of a change in the visual angle at the observer's eye. If the vertical scale predominates, it will seem smaller. If the horizontal area predominates, it will seem larger (a vertical chimney will seem smaller, an airfield will appear larger);

4. Reduce the rate of apparent motion of the terrain through the observer's field-of-view; and

5. Increase in visibility downward through the atmosphere to the target. The appearance of a target viewed vertically downward will be less affected by attenuation effects than one viewed obliquely from the same distance.

The most commonly found result is that performance tends to improve almost linearly as altitude increases up to some maximum. Dyer (1965) found that recognition ranges for vehicles and other tactical targets at 200 feet altitude were less than half those obtained at 500 to 1500 feet. The probability of detection was also slightly greater at higher altitudes. Of course, there is a limit beyond which increase in altitude will reduce performance. The maximum depends upon several variables including target size, apparent contrast as seen through the atmosphere, and the optimum altitude for visual target acquisition. Boynton hypothesizes that the optimum altitude is on the order of 250 times the linear size of the object being sought; under conditions of worst visibility it is on the order of 30 times the size of the object being sought. On the other hand, very low and slow flying aircraft can present additional problems. If the targets are unmasked at an altitude of 100 feet, there is a significantly higher probability of target recognition. This is apparently a result of the aspect angle of the target appearing very much like the way we normally perceive the world. Also, if the targets are camouflaged, detection data indicates lower probability of finding targets at the lower altitudes.

Vibration of the aircraft can also impair human visual acuity, and is a maximum at about 10-25 Hz. In most cockpit situations, vibration can be alleviated by head restraint.

The inherent design geometry of the cockpit, location of the cockpit in relation to the wings, engine nacelles and other obstructions can make a difference in what can be seen. Design requirements for fighter aircraft require a minimum of 11 degrees over the nose visual depression angle. The aircraft with the best visibility should, of course, be a prime candidate for a search mission[23].

CONCLUSION

In acquiring a target during a reconnaissance mission, the human observer has been found to perform this task the most efficiently and economically. Although automatic target detection methods are being pursued to take the place of the human observer, there has been no feasible method of developing a system which has the combined flexibility, programability, quick response, ability to reject clutter, ability to respond to small contrast, ability to respond to high and low ambient illumination, shape and contour matching ability, resolution, ability to detect anomalies in the scenic content, the ability to detect movement

[23] Marietta, M., pages 5.19 - 5.28.

and changes, and the ability to make intuitive judgments as the human observer. In addition, the small weight and volume make the human observer a very effective and economical sensor and data analyzer.

On the other hand, the observer becomes more vulnerable to our enemy defenses as he penetrates deeper into the threat area in order to obtain target information; thereby, increasing his probability of being killed. In order to decrease this probability and simultaneously increase the chances of accessing the target information in a timely fashion, the aircraft and sensor/display system will have to be optimally designed to take advantage of the human observer capabilities and deficiencies. Hopefully, in the future, technology will have developed a combination sensor of IR, radar, and TV simultaneously displayed on one screen. Such a sensor could be better tuned to the environment/target signature and, in addition, provide target information at greater standoff distances. This would have the effect of simultaneously decreasing target acquisition errors of the observer, as well as, decreasing acquisition times.

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